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THESIS

COMPUTERIZATION OF TACTICAL AIRCRAFT
PERFORMANCE DATA FOR FLEET APPLICATION

by

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June 1978

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Computerization of Tactical Aircraft
Performance Data for Fleet Application

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The nature of operations, variety of missions and configurations, and requirement for rapid response of fleet tactical aircraft has given rise to a unique problem within the Naval Aviation community, this being the interface between the aircrews and the aircraft performance prediction information supplied via charts and data in the Naval Air Training and Operating Procedures Standardization (NATOPS) Manuals. The data presented are not optimally used due to the method of presentation and the time and effort required to extract useful predictions. This investigation addressed the problem by developing a suitable method of NATOPS curve presentation that has sufficient simplicity and accuracy for application to current compact computers. The procedure is defined and numerical algorithsm produced which demonstrate the feasibility and desirability of this type of implementation.

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ACKNOWLEDGMENT

I. INTRODUCTION

This investigation was commenced in response to a
generally agreed upon, but not officially defined, fleet
problem, i.e., the interface between operational aircrews
and their aircraft performance prediction data. Currently,
in the rear sections of all fleet aircraft Naval Air Training
Operations and Standardization (NATOPS) Manuals [Ref. 5],
an extensive set of performance prediction charts are included
for aircrew use. An example of these charts for the A-7E
aircraft is included as Appendix A. These charts represent
performance predictions based upon interpolations and extrap-
olations of flight test data compiled at the Naval Air Test
Center, Patuxent River, Maryland. They are included in the
manuals for use by aircrews in the prediction of aircraft
performance items such as take-off roll and velocities,
cruise, emergency divert (Bingo), etc. The take-off pre-
diction parameters starting on page 11-36 of Appendix A will
be used as a representative example and have been prepared
on fold-out sheets for ease of reference. To predict take-
off parameters, the aircrew member must enter the chart on
page 11-36 of the NATOPS Manual with runway temperature and
pressure altitude. He must interpolate as necessary between
the given lines and proceed as in the dotted line example
(refer to the fold-out of Appendix A numbered 11-36) to
the chart for the appropriate double datum selection (an

engine parameter) to arrive at the corresponding take-off factor. With this number he must then proceed to page 11-37 and, after interpolating for gross weight correction, proceed as indicated to arrive at the basic ground roll distance. Proceeding to page 11-38, he next must apply a correction for relative humidity, utilizing the relationship in the appropriate paragraph, followed by tracing through subsequent graphs to correct for relative wind (which is computed from given tower winds and runway heading), runway slope, center of gravity position, and trailing edge flap position. Similar graphical procedures exist for all other aircraft performance predictions. A compact equivalence of these charts, known as "Pocket Check Lists", are carried by all aircrews in flight for ready reference. In actual practice individual squadrons have generated numerous NATOPS data cards which represent normally encountered conditions and were derived from the NATOPS charts. In the take-off data prediction example ten input parameters were required to compute take-off roll and velocity. Using the charts has proven to be cumbersome, time consuming, and prone to error. The use of pocket check lists is more convenient but less accurate, and the individual squadron knee-board cards cover only a few nominal situations. The computation of take-off roll is relatively simple when compared with determining the parameters to establish an optimum flight profile for a complex weapons delivery mission. The aforementioned complex

problem involves a similar use of cruise, drag count, climb

and descent, etc. charts. As a further illustration of the

problem's magnitude, the former Director of the School of

Aviation Safety at the Naval Postgraduate School, Monterey,

California, has repeatedly required that each member of a

one-week Command Safety Course (prospective squadron commanding

officers) complete the weapons delivery problem included

here as Appendix B. Tnis is considered as a typical fleet

contingency planning problem, requiring that in one hour

these experienced aviators compute the maximum mission

range with the given inputs and aircraft parameters. The

results of these tests, given to a class of sixteen such

aviators, were described by the Director as [Ref. 3]:

> "It is a startling but typical fact that
> the correct answer of 538 NM was not
> achieved by any member of the class.
> The closest answer was in error by 126
> miles and the spread of answers ranged
> from 336 to 868 NM. Additionally the
> correct answer was attained by the class
> instructor only after a measured 16 hours
> of effort with the NATOPS Manual."

The preceding example serves as a graphic illustration of

a widely accepted problem, the elements of which may be

summarized as:

1. The only complete and accurate performance

prediction data available to fleet aircrews are

those provided by the performance chart sections

of the appropriate aircraft NATOPS Manuals.

2. Experienced fleet aviators do not use the source information for daily computation of NATOPS problems with enough regularity to insure competency.

3. Personal experience and interviews with fleet aviators indicated that the NATOPS performance presentation contained highly useful and vital data but was too cumbersome, and data extraction too time consuming, for regular operational use.

The purpose of the studies described herein was to examine an alternate approach for assisting the aircrew member to solve the various aircraft performance problems which are required for safe and effective operation of a Naval aircraft in fulfilling its' mission. The subsequent discussion will proceed with the assumptions made, the method used for the solution, and the results of this study.

II. DISCUSSION

A. GUIDELINES

At the onset of the investigation a set of guidelines
was adopted to limit its scope and provide a definitive
goal. This was deemed necessary because of the controversy
within the aviation community over all facets of NATOPS
including the validity of some of the data. It was beyond
the scope of this investigation to question that validity
or investigate any reported discrepancies.[1] The most
current NATOPS data available are the official fleet stan-
dard and it was merely the representation of those data
that inspired this study. Thus, from the above discussion
the first guideline was defined:

1. Any method of representation of NATOPS data must
   be compared to the officially published NATOPS data
   for accuracy and completeness.

Throughout the life cycle of an aircraft, numerous
changes to the NATOPS procedures and performance data are
published which represent revisions due to lessons learned
through extensive operating and testing. The realization
of this fact led to guideline number two:

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[1]During the course of this investigation several such
discrepancies were found and changes submitted in accordance
with existing change submittal procedures.

2. To remain useful and current, any system of
data presentation must be adaptable to changes as
they are promulgated.

The mission variety and uniqueness of carrier based,
single-seat aircraft, especially under emission control
conditions, make it highly desirable that the information
contained in NATOPS be readily available to the pilots while
in the aircraft. Airborne workload, lack of additional
cockpit space, and lack of time in critical situations led
to the third guideline:

3. The data presentation system utilized must be
light, small, simple to use, reliable, and require
a minimum amount of pilot's attention during use
to insure acceptability from the standpoints of
mission accomplishment and flight safety.

Finally a standard of measurement was defined for
accuracy comparison with NATOPS data. These figures were
chosen based upon the experience of the author, and were
used to determine when the degree of complexity of the
computer solution was adequate for this application.
Guideline four lists the desired computational tolerances.

4. One knot of airspeed
   100 feet of altitude of ground-roll distance
   100 pounds of weight
   Ten seconds of time
   100 pounds of fuel

After defining the above, an investigation was commenced toward utilizing digital computers as a solution, with the goal being the reduction of the data contained in NATOPS into an algorithm for use in desk , "hand-held", and/or existing on-board aircraft calculators and computers. Informal liaison with senior and junior attack and fighter fleet aviators has indicated strong support for a solution of this type when restrained to the stated guidelines.

B. COMPUTATIONAL METHOD USED

Procedurally the entire project was subdivided as follows:

1. Investigation of a numerical technique for general computer use.

2. Application of thst numerical technique to specific aircraft performance data

3. Investigation of hardware and implementation of the results of part 2, above, for fleet use.

This investiagation was principally concerned with step 1, above, while subsequent and concurrent investigations were proceeding with the work in the other areas. Two basic techniques were investigated:

1. Data Storage

2. Computational technique

Data storage, while mathematically trivial, was
determined to be unacceptable for this application due to
the amount required to insure completeness. An examination
of a set of curves (e.g., take-off) showed a near infinite
number of solutions for the ten input variables used. The
current squadron method for bypassing NATOPS by using knee-
board cards for quick reference to nominal solutions corres-
ponds to the data storage method on a much smaller scale.
While many more data points could be stored utilizing calcu-
lators, it was felt that a table lock-up solution would lead
to incorrect interpolation and extrapolation when seeking
information utilizing parameters other than the ones stored.
Interpolation routines could be utilized when this occurred,
but each routine would vary depending upon the relationship
of the data points. In many cases the data vary in a differ-
ent non-linear manner, thus causing the number of routines
used to be unacceptably large in order to produce the desired
results. Additionally, the number of storable points is
limited by computer size. Fleet tactical aircraft continually
operate with widely varying fuel, gross weight and drag
coefficient values. These parameters greatly affect nearly
all computations made. The data storage method for mission
planning purposes would require a near infinite number of
precomputed solutions using these parameters, and would
therefore be too complex for use. Finally the computer
state-of-the-art was sufficiently advanced to and even

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beyond the capability for computing the performance of any number of inputs, utilizing a fraction of the memory space required for data storage.

The data storage method, after a brief trial, was not investigated further. A summary of the reasons for this decision would include:

1. The number of variables involved would require too much data storage space to produce the desired result.

2. A reduced set of data would be of little value in mission planning situations due to the accuracy of the required results.

3. Inaccurate (and thus unsafe) interpolation and extrapolation of the stored data would be a natural out-growth of this type of system (similar to the current use of knee-board cards).

4. Computer programming state-of-the-art was far advanced beyond the requirement for this type of method.

The computational method was considered to be well within the capability of "hand-held" calculators from both memory size and computational standpoints. The basic steps for the implementation of this method are listed below:

1. Reduce the individual curves or sets of
data to analytical expressions.

2. Coordinate these expressions, of each of
the above, to output the dependent variable
for each chart or family of curves, providing
for interpolation between the curves.

3. Coordinate the inputs and individual curve
outputs into a computer program for validation
and pilot use.

The method used for reducing the curves and charts to
analytical expressions was simply the Least Squares Fit
method. A precise explanation of this method can be found
in Refs. 1 and 2. Appendix C contains a brief explanation
and sample application of the technique. The majority of
the curves or data sets found in NATOPS could be sufficiently
described by first, second, or third degree polynomials.
This fact was assumed from intuition and supported by numer-
our iterative curve fits. A variety of computer programs
were in existence to aid in producing the desired solutions.
The Hewlett-Packard (HP) 9830 desk calculator had available
one such program and was used for this analysis (c.f.,
Reference 6 for a detailed description and set of instruc-
tions for use of this technique). Prior to commencement of
the data reduction, photographically enlarged versions of
the charts under investigation were obtained to aid in the

precise recording of information. Using these charts the
following procedure was utilized to produce the analytical
expressions for each individual curve:

    1. Record data points from each curve of
a family of curves presented on the chart
(Refer to the foldout charts for take-off
prediction provided in Appendix A).

    2. Utilize these points in the HP polynomial
regression program to generate the coefficients
of the analytical expression of sufficient
degree for the curve being analyzed.

    3. Use the coefficients generated to check
polynomial accuracy when compared to the
NATOPS curves.

    4. Iterate the procedure, reducing the degree
of the polynomial in an attempt to simplify the
expressions and retain sufficient accuracy to
comply with the specifications of guideline 4.

    Once a set of equations was obtained for a family of
curves, an investigation was commenced to determine a
simple method of coordinating the curves, and providing
a method of producing an output for those input parameters
which might fall between the curves of a family. This pre-
sented the greatest problem. The curves of the top chart

on page 11-38 of Appendix A were used as an example (fold-out provided). Given the set of five polynomial expressions corresponding to the respective curves for runway pressure altitude, a linear interpolation routine was produced and tested to predict values between the curves. This routine represented the first attempt at providing a means of accurately computing values between the curves. The independent variables were the pressure altitude and the runway temperature. Using the interpolation routine for a pressure altitude of 2,595 feet and 95 °F, for example, the program first calculated the output from the 2,000 foot curve polynomial. It then did the same for the 4,000 foot polynomial and linearly interpolated to find a value for the original input of 2,595 feet. This procedure produced unacceptable results for the reasons stated in the following:

1. The linear interpolation was not a true model of the actual variance between the curves. A visual inspection revealed that the spacing between the curves increased with altitude. An attempt was made to correct the effect by multiplying the result by a complicated bias factor with analytically acceptable results. The method used to arrive at this factor was highly iterative and time consuming and not considered an acceptable procedure considering the number of curves to be analyzed.

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2. Additionally the program required for selecting the curves for interpolation for a given input, complete with interpolation routine, was considered too lengthy and repetitive for small calculator use. This would be especially critical if the family of curves contained many individual curves, as do those on page 11-38 of Appendix A.

Given that the method of linear interpolation between curves of a family was unacceptable for the reasons above, an alternate method of expressing a family of curves analytically was investigated. This method was suggested by Lt. Keith Winters [Ref. 4]. It will be explained using the example contained in the following paragraphs.

The problem was to take a set of polynomials of the same degree representing a family of curves and reduce these to an equation or small set of equations that would generate a solution for these polynomials or any value in between the curves they represent.

Given was a set of equations for the five curves of the previous example (all of the same degree) of the form

$$Y_1 = A_{11} + A_{12}X + A_{13}X^2 \ldots A_{1N}X^{N-1}$$

$$Y_2 = A_{21} + A_{22}X + A_{23}X^2 \ldots A_{2N}X^{N-1}$$

$$\vdots$$

$$Y_m = A_{m1} + A_{m2}X + A_{m3}X^2 \ldots A_{mN}X^{N-1}$$

or more specifically for this example

$$Y_1 = A_{11} + A_{12}X + A_{13}X^2 + A_{14}X^3 \qquad \text{0 feet pressure altitude}$$

$$Y_2 = A_{21} + A_{22}X + A_{23}X^2 + A_{24}X^3 \qquad \text{1000 feet}$$

$$Y_3 = A_{31} + A_{32}X + A_{33}X^2 + A_{34}X^3 \qquad \text{2000 feet}$$

$$Y_4 = A_{41} + A_{42}X + A_{43}X^2 + A_{44}X^3 \qquad \text{4000 feet}$$

$$Y_5 = A_{5;} + A_{52}X + A_{53}X^2 + A_{54}X^3 \qquad \text{8000 feet}$$

The A_{mn} terms were the polynomial coefficients produced by the Least Squares Fit program for each curve of chart 1. The Y_m terms were the fictitious numbers assigned as the output dependent variables of chart 1 (input to chart 2) and X was the independent variable, temperature, of the same example. Again it was desired that, given any altitude and temperature within the chart limits, a Y could be computed precisely. To do this the program must first take the given altitude and generate either computationally, or from memory, the coefficients of the corresponding third degree polynomial. To provide for the computation of these coefficients separate plots were made of the A_{m1}, A_{m2}, A_{m3} and A_{m4} coefficients using their corresponding input altitude values as abscissae. Figure 1 illustrates the concept.
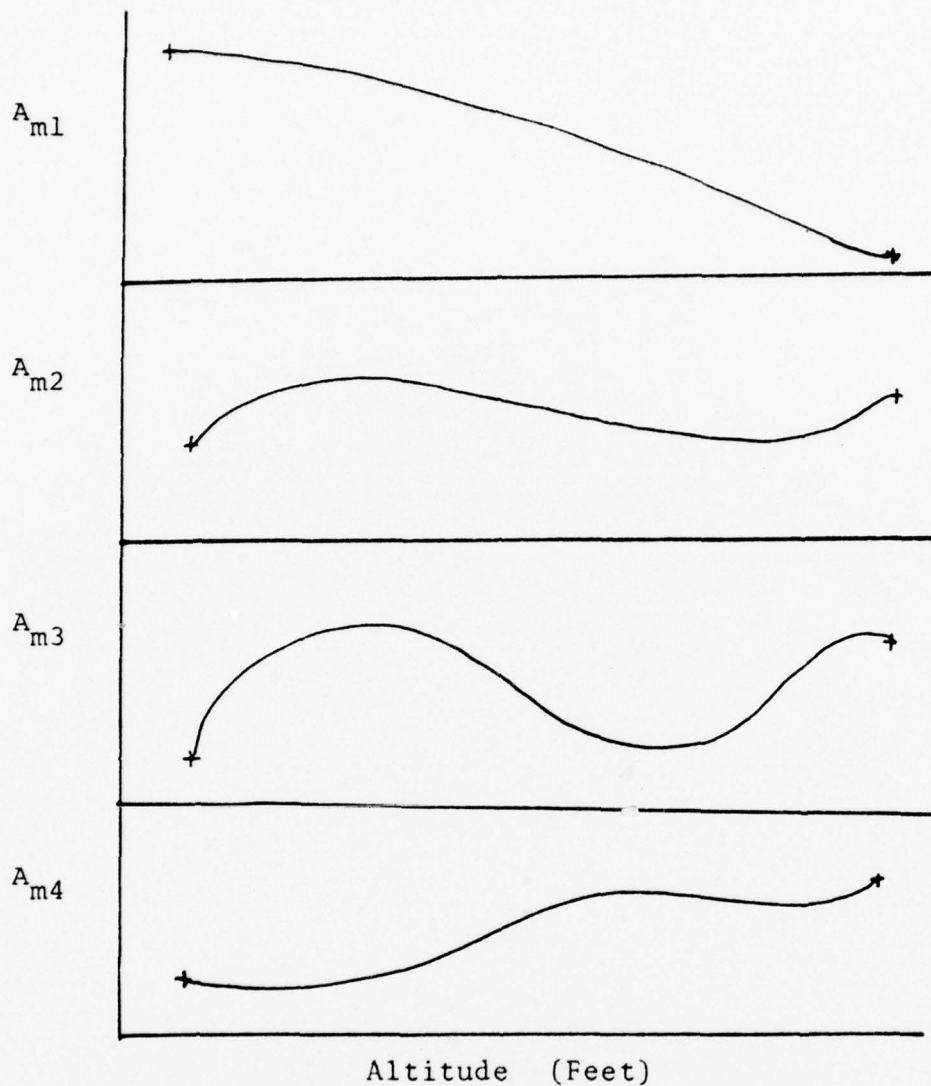
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Figure 1. Altitude versus polynomial coefficients
for a series of third degree equations

Since each curve contained five data points, a fourth

degree (or co-location) polynomial was plotted and the

coefficients produced by the HP 9830 program. With

these coefficients (Bcd) equations of the form below

were produced:

$$A_{m1} = B_{11} + B_{21}M + B_{31}M^2 + B_{41}M^3 + B_{51}M^4$$

$$A_{m2} = B_{21} + B_{22}M + B_{23}M^2 + B_{42}M^3 + B_{52}M^4$$

$$A_{m3} = B_{31} + B_{32}M + B_{33}M^2 + B_{43}M^3 + B_{53}M^4$$

$$A_{m4} = B_{41} + B_{42}M + B_{43}M^2 + B_{44}M^3 + B_{45}M^4$$

These equations when used with the following equation

$$Y = A_{m1} + A_{m2}X + A_{m3}X^2 + A_{m4}X^3$$

would produce the desired output for any value of temperature and altitude. The following chart of symbol definitions was included to ensure clarity:

M   = Any value of pressure altitude between 0 and 8000 feet

x   = Any value of temperature between 0 and 120°F

Y   = The fictitious number representing the output of chart 1 for any given input

Bcd = Coefficients of the polynomials used to predict the corresponding coefficient of the Y polynomial for any given input pressure altitude (M)

A_{mn} = The coefficient of the x polynomial used to generate the output number of chart 1 from the given temperature.

The task of the person attempting to program a set of NATOPS curves using this technique is summarized below:

1. Generate the coefficients for each curve by:

    a. Recording data points from the curves.

    b. Utilize a computer solution or manually fit the points to output a polynomial of the same degree representing each curve.

2. Plot the similar coefficients of each curve as a dependent variable against the corresponding independent variable as was done in Figure 1.

3. Obtain polynomial expressions of sufficient degree for each of these coefficient curves.

4. Write a computer algorithm that will perform the following:

    a. Utilize the polynomials of step 3 to generate the coefficients of the polynomials of step 2.

    b. Utilize the coefficients generated in step 4a. in a polynomial that will output the independent variable of a family of curves.

These steps are a general description of the successful procedure which was generated by this investigation. A detailed example using actual numbers has been included in the next section for reference purposes. Throughout this explanation, emphasis has been placed upon the need for

interpolating accurately for any value within the given

curves. The method used also provides for mathematic

extrapolation outside the limits of the given NATOPS curves.

Care was taken not to provide for this extrapolation in

any of the programs generated by this technique. This was

done either by limiting the range of the independent varia-

bles which the program would accept to values within the

stated NATOPS limits, or by ensuring that the output of

each separate calculation did not exceed the corresponding

chart limits. Mathematical extrapolation of NATOPS data,

without flight test verification and approval from the Naval

Air Test Center, can lead to a computer prediction that does

not correspond to aircraft performance. While precise

interpolation is well within the capability of the process

developed by this investigation, extrapolation in this case

is dangerous and was not within the intent of the study.

C. DETAILED EXAMPLE OF THE COMPUTATIONAL METHOD

The computational steps listed on page 24 were performed

for the take-off charts of the A7E NATOPS manual and were

included as an example. The number designation of each

step corresponds to the instruction as listed. The problem

was to generate a set of equations that would describe the

family of curves on page 11-36 (Top chart) of Appendix A

and provide for interpolation between all curves to output

the dependent variable[2] to be used in the subsequent chart
on that page.

la.   The data shown below were extracted from
       the top chart of page 11-36 Appendix A.

Alt (Feet)	0	2000	4000	6000	8000
Temp°F					
0	13.6	12.6	11.4	10.0	8.3
20	13.3	12.4	11.2	9.8	7.9
40	12.9	11.9	10.5	9.1	7.1
60	11.9	10.8	9.3	7.4	5.2
80	10.6	9.1	7.2	4.8	1.6
100	8.5	6.6	4.2	–	–
120	5.0	–	–	–	–

lb.   These data were entered into the afore-
       mentioned HP 9830 computer program,
       producing the following coefficients of
       a third degree polynomial of the form

$$Y = A_{m1} + A_{m2}X + A_{m3}X^2 + A_{m4}X^3$$

where

       m = altitude

       X = temperature

─────────────────────────────
[2] It may be noted that the chart used does not have printed
values for the dependent variable. In NATOPS curves these are not
required since the normal procedure is to proceed graphically from
chart to chart. For the numerical analysis of this study a set of
fictitious numbers was assigned to the dependent variable of this
chart and to the independent variable of chart 2 page 11-36.

Coefficients	A_{m1}	A_{m2}	A_{m3}	A_{m4}
0	1.3×10^1	-1.9×10^{-2}	1.9×10^{-4}	-5.2×10^{-6}
2000	1.2×10^1	-1.6×10^{-3}	-2.9×10^{-4}	-2.9×10^{-6}
4000	1.1×10^1	-3.1×10^{-3}	-3.2×10^{-4}	-3.7×10^{-6}
6000	1×10^1	4.5×10^{-3}	5.4×10^{-4}	-4.2×10^{-6}
8000	8.3×10^0	-2.0×10^{-2}	2.8×10^{-4}	-1.4×10^{-5}

2.   The coefficients were then plotted against altitude as depicted in Figures 2, 3, 4, and 5.

Altitude

Figure 2: A_{m1} versus Altitude
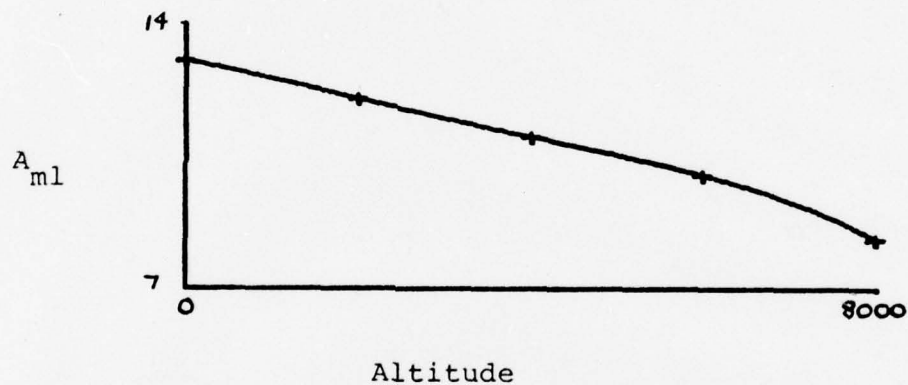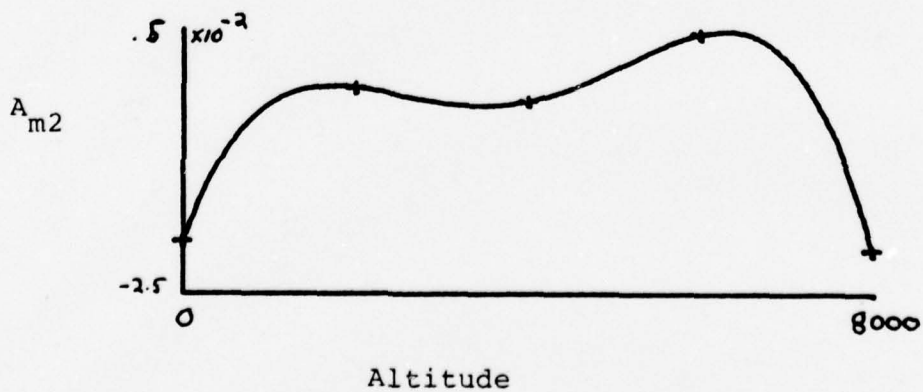

Altitude

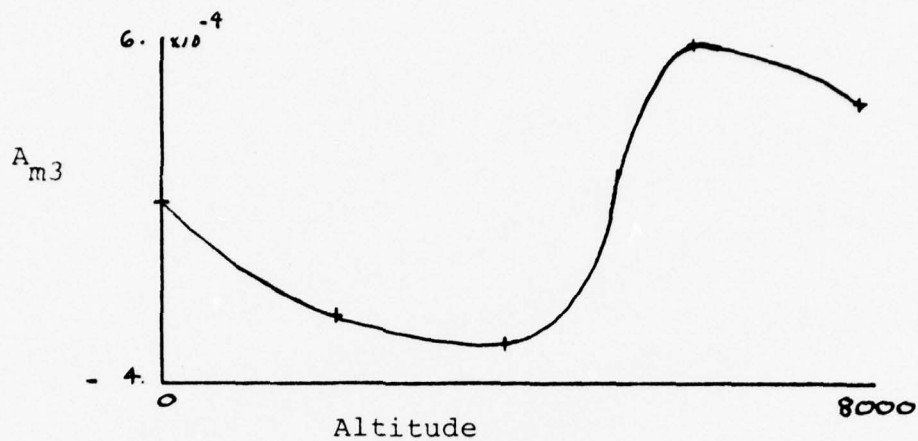Figure 3: A_{m2} versus Altitude

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Figure 4: A_{m3} versus Altitude
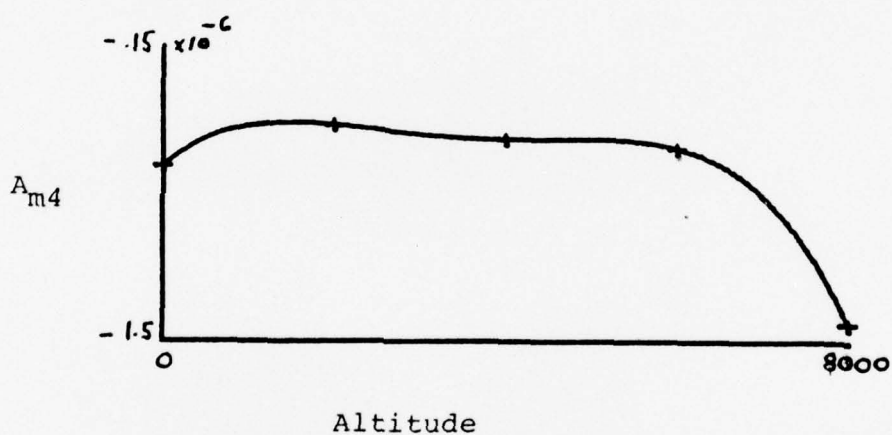

Altitude

Figure 5: A_{m4} versus Altitude

3.   Using the HP 9830 computer program as
      above the coefficients of each of these
      third degree curves were generated and
      placed in the following polynomials
      of the form:

$$A_{mN} = B_{m1} + B_{m2}m + B_{m3}m^2 + B_{m4}m^3$$

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where

$$m = \text{Altitude (Feet)}$$

$$A_{m1} = 13.1 - 1.7\text{x}10^{-4}m - 2.1\text{x}10^{-7}m^2 + 3.7\text{x}10^{-11}m^3$$

$$A_{m2} = 4.5\text{x}10^{-2} - 7.9\text{x}10^{-6}m + 3.8\text{x}10^{-9}m^2 - 9.7\text{x}10^{-13}m^3$$

$$A_{m3} = 1.3\text{x}10^{-3} - 8.2\text{x}10^{-7}m + 4.1\text{x}10^{-10}m^2 - 8.5\text{x}10^{-14}m^3$$

$$A_{m4} = 1.9\text{x}10^{-5} + 1.4\text{x}10^{-8}m - 9.5\text{x}10^{-12}m^2 + 2.0\text{x}10^{-15}m^3$$

4a.b. The enclosed computer program (following
the Appendix) satisfies the requirements of
steps 4.a and b, page 24. It coordinates
all the input variables needed for computing
take-off velocity and ground roll distance,
and outputs those values within the accuracy
required by Guideline 4 of page 13.

III. <u>RESULTS</u>

The results of this investigation were that:

1. A technique for reducing families of
curves found in NATOPS manuals to simple
equations that provide for proper interpolation
was developed and tested.

2. A sample program for an entire performance
example was prepared to illustrate the use of
the polynomials in generating a solution to a
typical performance problem.

The computational technique was utilized in providing
coefficients for polynomials for all families of curves
required to compute take-off roll and velocity for the A7E
aircraft. A list of the program steps was included as an
enclosure to this thesis. The curves of the charts for
the ten input parameters were treated in a manner similar
to the example of the previous section.

As can be seen from the equations of each section of the
enclosed program the number of polynomial expressions re-
quired to describe a family of curves is not related to the
number of curves within the family. Rather, it is a function
of the degree of the curves within the family. If the degree
of the curves were represented by the letter w, then the
number of equations required (s) would be

$$s \;=\; w + 2$$

This fact caused significant reduction in the size, and an increase in the computational accuracy, of the final program. To illustrate an extreme example, the family of curves associated with computing the take-off distance wind correction will be referenced. It can be seen from this family (Located in Appendix A, page 11-38) that fifteen second degree curves were utilized to describe this correction. The total number of curves required to compute the correction using the method of this investigation was

$$s \;=\; 2 + 2 \;=\; 4 \;.$$

This included the three equations for computing the coefficients and one equation for coordinating the coefficients and computing the dependent variable from the output of the previous algorithm. It is worthwhile at this point to emphasize that these four equations were not only valid for the data that formed the given curves, but also for any intermediate values retaining the same accuracy. Alternate methods of using equations for all fifteen curves, plus a discrimination and interpolation routine, would produce less accurate results and require more computer space.

The sample program for take-off velocity and distance computation was implemented for demonstration purposes for the HP 9830. The program and computer combination met all

the requirements set forth in the guidelines with respect
to ease of use, accuracy, speed, reduced memory required,
and all around desirability. Informal tests with fleet
aviators demonstrated that the program produced the same
results as the charts but required less time by an order
of magnitude, and little or no user effort. Implementation
of the entire set of NATOPS curves on the HP 9830 desk
computer would be unsuitable for aircraft use but could
provide preflight and contingency planners with an invaluable
tool for ground and shipboard use.

Concurrent investigations were performed in this area
by Major J.D. Restivo, USMC, and Lt G.L. Koger, USN, at the
Naval Postgraduate School. Major Restivo applied the tech-
nique of this thesis to the A6 aircraft NATOPS curves, while
Lt Koger implemented the entire set of A7E curves in a
"hand-held" calculator, namely, the Texas Instruments
TI 59.

With the completion of this thesis, the feasibility
of reducing the NATOPS performance data and curves has
been demonstrated, and a procedure documented for the
process. The responsibility for further investigation in
this area has been assumed by Commander, Light Attack Wings,
Pacific (COMLATWINGSPAC), Naval Air Station, Lemoore,
California. To this end the following conclusions and
recommendations are included as the final section.

IV. <u>CONCLUSIONS AND RECOMMENDATIONS</u>

It is concluded from this investigation that adaptation of the NATOPS performance data to digital computers for aircrew use was entirely feasible. Furthermore, a simple procedural method was found and demonstrated for reducing a large family of curves to a minimum number of polynomial expressions which could be coordinated in a program for precisely computing aircraft performance for any variation of the input parameters. Finally, it was shown that the computerized method of NATOPS presentation produced a quick and easy method for aircrews and planners to predict aircraft performance for missions and contingencies.

The following recommendations are made as a result of this study:

1. The activity which has been assigned the task of managing the research, development, and procurement for use by tactical aircraft crews should consider the procedures developed in this thesis study for achieving the end result.

2. Funds should be provided for a coordinated Navy-wide effort to ensure standardization of technique and hardware to reduce redundant efforts in this area of rapidly increasing interest.

TAKEOFF FACTOR (A-7E)

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL.
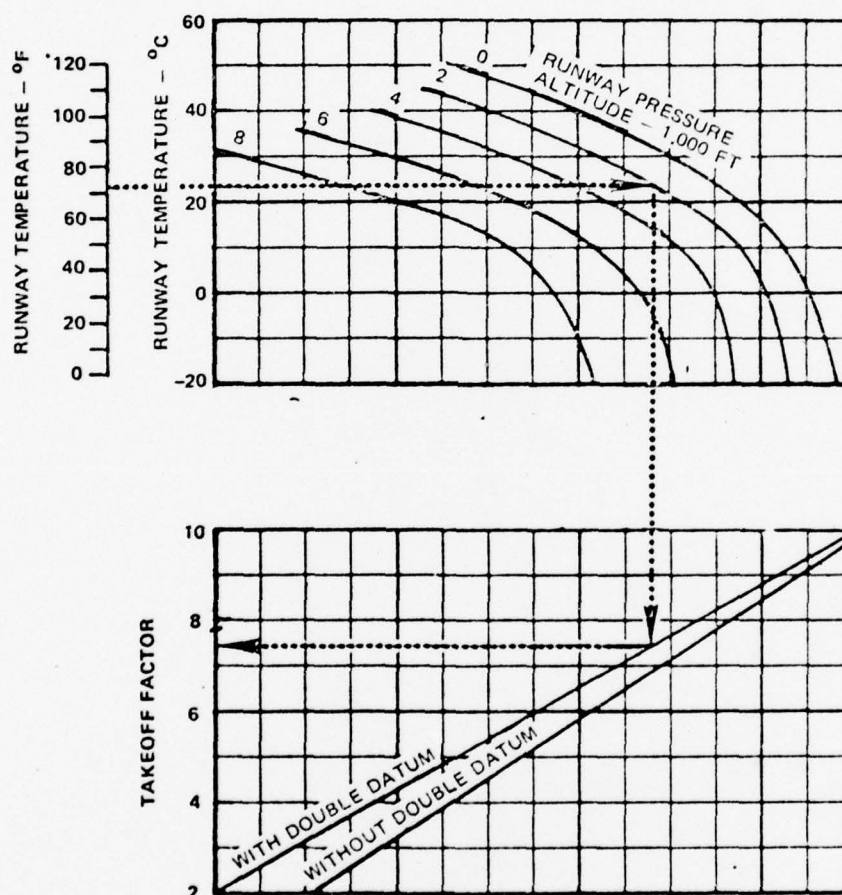
76E286-04-74

Figure 11—11

11—36

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TAKEOFF GROUND ROLL DISTANCE (A-7E)

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

CONDITIONS:
LEVEL HARD SURFACE RUNWAY
MILITARY RATED THRUST
LANDING CONFIGURATION
ZERO HEADWIND
CG: 26% MAC
FULL FLAPS

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

NOTE

For minimum ground roll corresponding to minimum lift-off speed, subtract 500 feet.

For humidity effects on takeoff distance, ground roll distances should be increased 1% for each 10% increase in the relative humidity above 40%.

76E287(1)-04-74

Figure 11-12 (Sheet 1)

11-37

TAKEOFF GROUND ROLL DISTANCE (A-7E)

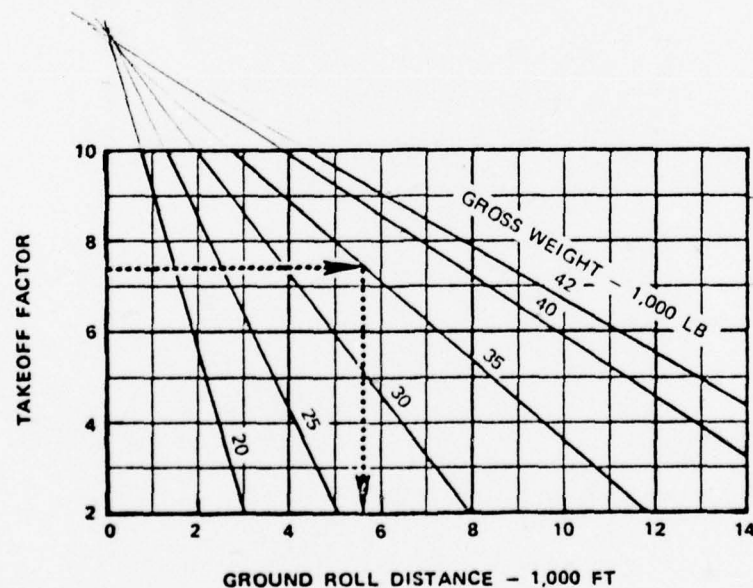## ADJUSTED GROUND ROLL DISTANCE

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

CONDITIONS:
HARD SURFACE RUNWAY
MILITARY RATED THRUST
LANDING CONFIGURATION
LEADING EDGE FLAPS DOWN

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL.

NOTE

For humidity effects on takeoff distance, ground roll
distances should be increased 1% for each 10% increase
in the relative humidity above 40%.

GROUND ROLL DISTANCE — 1,000 FT
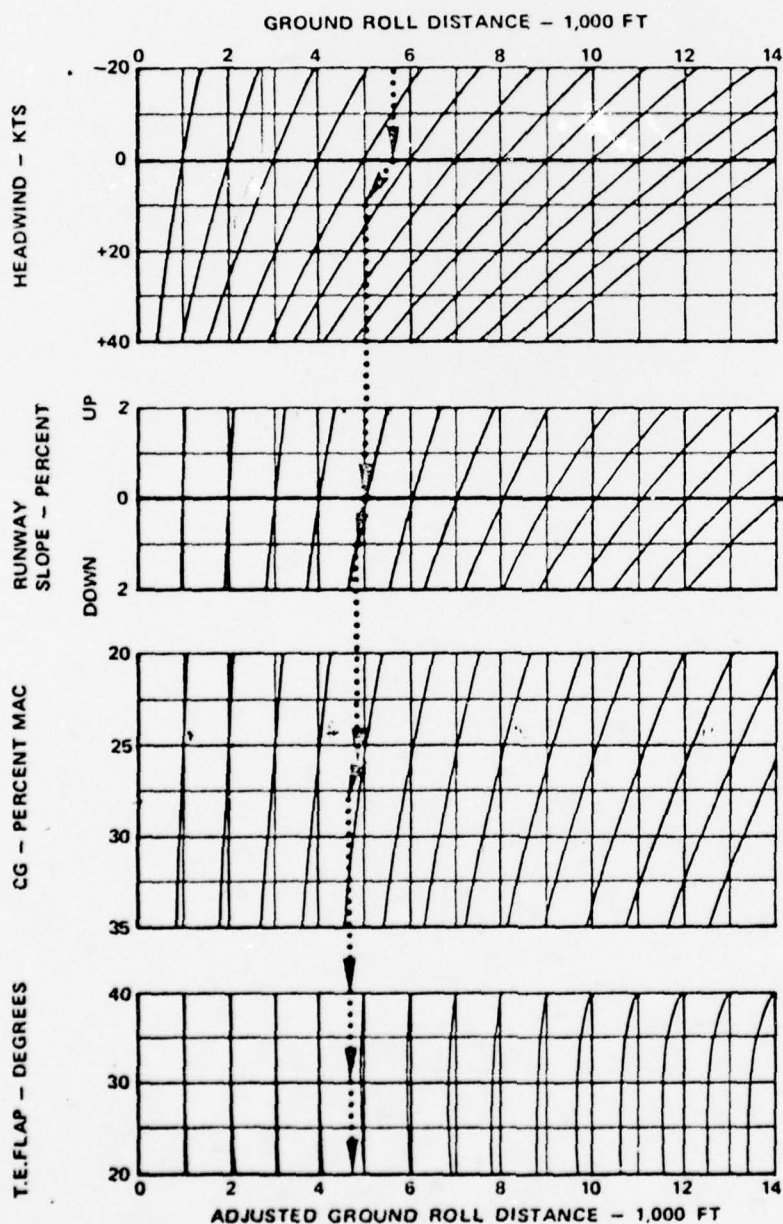
Figure 11-12 (Sheet 2)

76E287(2)-01-72

11-38

TAKEOFF SPEED (A-7E)

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

CONDITIONS:
MILITARY RATED THRUST
LANDING CONFIGURATION
LEADING EDGE FLAPS DOWN

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

NOTE

Data basis is 26% MAC. Increase speed 1/2 knot per 1% forward CG shift. Decrease speed 1/2 knot per 1% aft CG shift.

NOTE

For minimum ground roll subtract 6 knots.

CG 26% MAC

CG 26% MAC

NORMAL TAKEOFF

INITIAL STALL WARNING – 20.5 UNITS AOA

VELOCITY – KIAS

T.E. FLAPS – DEGREES

GROSS WEIGHT – 1,000 LB

Figure 11–13

76E354-02-72

APPENDIX B

A-7 NATOPS PROBLEM

An international incident has occurred which necessitates the rapid protection and extraction of U.S. military personnel within the strife stricken country.

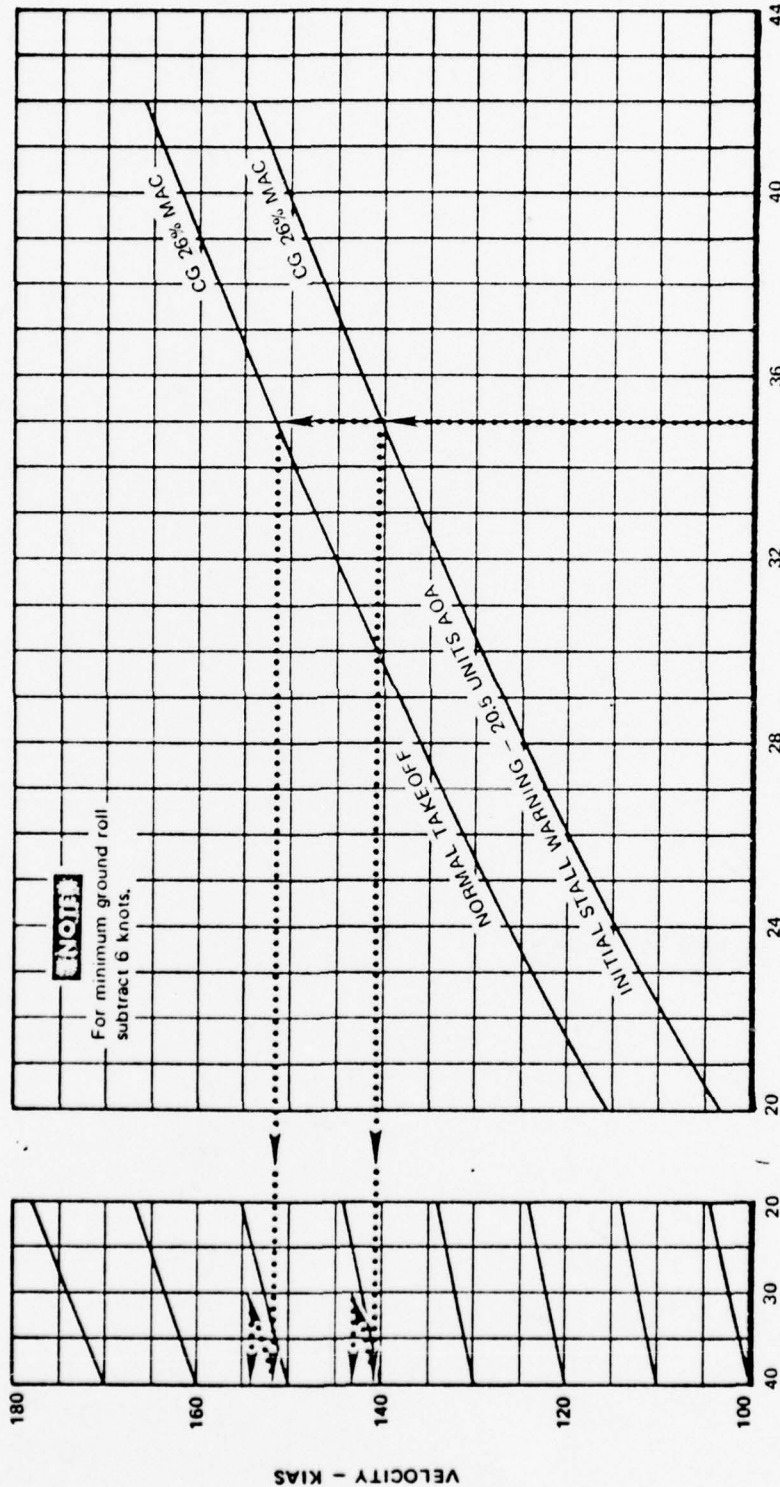You are the Commander of an A-7E squadron and have been given the task of planning and conducting the missions in support of the extraction of the U.S. personnel. Given the following information, determine the greatest distance from the target at which you could launch and return to the same take-off point.

1. Fuel Load - 14,000# (2,000# in each aero I D)

2. Ordnance Load

    a. 1 AGM-45 (Skrike) on Sta #1 and Sta #8

    b. 3 MK-20 (Rockeye) on Ter on Sta #2

    c. 1 Aero I D (Full JP5) on Sta #3 and Sta #6

    d. 1 AIM 9D (Sidewinder) on Sta #4 and Sta #5

    e. 3 MK-83 (LDGP) on Ter on Sta #7

3. Basic Aircraft Weight - 21,000#

4. Area temperature at sea level - 30°C

5. Use 300# fuel for Start/Taxi/Catapult

6. Rendezvous at 10,000' and 25 NM - use 800# fuel during rendezvous

7. Descend from cruise altitude to target
    a. Descend to 12,000'
    b. Use 2,700#/Hr fuel flow
    c. Maintain 370 Kts ground speed
    d. Begin descent at 40 NM

8. Enroute winds are forecast
    a. To the target - 40 Kts headwind
    b. Return to ship - 70 Kts tailwind
    c. Descents - no wind

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9.   Use 2,000# fuel in target area

10. Expend the following ordnance
     a.   2 AGM-45
     b.   3 MK-20
     c.   3 MK-83
     d.   Retain all other racks, ordnance, tanks

11. Climb to cruise altitude for return will be from sea
     level.

12. Plan for Charlie on arrival with 1,000# internal fuel
     on the ball.

The following charts and tables have been taken from the
NATOPS for your use.

APPENDIX C

Least Squares Fit Approximation

References 1 and 2 describe the Least Squares Fit
Approximation in detail. In general the problem is to
represent a set of "n" data points in two dimensional space

$$X_i, \quad Y_i \quad i = 1 \text{ to } n$$

by a polynomial expression of a curve whose degree is less
than "n". Two classes of problems exist:

1. Linearly independent - Those in which the
   degree (d) of the polynomial is one less
   than the number of data points

$$d = n - 1 \qquad (1)$$

2. Linearly dependent - Those in which the degree
   (d) is less than n-1

$$d < n - 1 \qquad (2)$$

As an example, a set of four (4) data points randomly
spaced was chosen. If a third degree polynomial of the
form

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$$Y = A + BX + CX^2 + DX^3 \qquad (3)$$

were desired, and the data points X_i and Y_i were inserted
(i = 1 to 4) into four such equations, an exact solution
for the four unknown coefficients would exist. These four
unknowns could be found from the four equations by numerous
conventional techniques (Direct substitution, Cramer's rule,
etc.). The polynomial expression generated would be termed
a "col-location" polynomial because its plot would pass
through all data points.

   It is often advantageous to describe a set of data points
by a curve that does not pass through each point. This
type of polynomial would be termed a "regression" equation.
For any set of data points an infinite number of regression
expressions exist for any specified degree (except the
linearly independent case) and the object of the Least Squares
Method is to find the polynomial coefficients of the chosen
degree that best describe the data points. In the previous
example of four data points, assume that, instead of the
third degree form chosen, a second degree equation were
selected of the form

$$Y = A + BX + CX^2 \qquad (4)$$

With four data points, the polynomial is overspecified and
thus linearly dependent. For this case an infinite number

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of solutions exist for the coefficients a, b and c. If
an error term (δ) were defined for any given X,Y pair as

$$\delta_1 = |Y_1 - A + BX_1 + CX_1^2| \qquad (5)$$

a total squared error term (E) could then be defined by
squaring and summing the   terms attained:

$$E = \sum_{i=1}^{N} \delta_1^2 \qquad (6)$$

If E were then minimized for any given degree chosen, the
best Least Squares Fit would have been achieved.

   If the values for δ from equation 5 were inserted in
equation 6 and the partial derivative of E were taken with
respect to the coefficient A an equation would be generated
that when set equal to zero (0) would define a minimum
value of E for a given value of A. If the same operation
were performed with respect to the coefficients B and C then
three equations would be generated with three unknowns (A,
B, and C). The solution of these simultaneous equations
would produce the coefficients A, B, and C, that would
minimize the value of E and hence would produce a Least
Squares Fit approximation to a set of linearly dependent
equations.

   A numberical procedure has been developed to accomplish
this task. An example of this procedure has been included
in the following paragraphs [Ref. 1 and 2].

Least Squares Fit Method Example

Given the following set of data:

	X	0	1	2	4	7
f(X) = Y		0	1	3	12	20

fit a curve of the form

$$f(X) = Y = A + BX + CX^2$$

Step 1:   Substitute all pairs of data into the form equation yielding the fact that the coefficients (A, B, & C) must satisfy all the following:

$$0 = A + B(0) + C(0)^2$$
$$1 = A + B(1) + C(1)^2$$
$$3 = A + B(2) + C(2)^2$$
$$12 = A + B(4) + C(4)^2$$
$$20 = A + B(7) + C(7)^2$$

Now multiply each expression by its coefficient of A in that expression and add all equations yielding

$$36 = 5A + 14B + 70C$$

Now multiply each expression by its coefficient of B in that expression and add all the expressions yielding

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$$0 = 0(A) + 0(B) + 0(C)$$

$$1 = A + 1B + 1C$$

$$6 = 2A + 4(B) + 8(C)$$

$$48 = 4A + 16(B) + 64(C)$$

$$\underline{140 = 7A + 44(B) + 343(C)}$$

$$195 = 14A + 70(B) + 416(C)$$

Now multiply each expression by its coefficient of C in that expression and add all the expressions yielding

$$0 = 0(A) + 0(B) + 0(C)$$

$$1 = 1(A) + 1(B) + 1(C)$$

$$12 = 4(A) + 8(B) + 16(C)$$

$$192 = 16(A) + 64(B) + 256(C)$$

$$\underline{980 = 49(A) + 343(B) + 2401(C)}$$

$$1185 = 70A + 416B + 2674C$$

Now solve the following three previously generated equations for the coefficients A, B, & C yielding

$$36 = 5A + 14B + 70C$$

$$195 = 14A + 70B + 416C$$

$$1185 = 70A + 416B + 2674C$$

$$A = -.99, \quad B \approx 2.6, \quad C = .065$$

and

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$$Y = -.99 + 2.6X + .065X^2$$

The following chart and plot depict the original data and the data obtained from the equation for the fitted curve:

	Original	Fitted Curve Polynomial
X	Y	Y
0	0	-.98
1	1	1.67
2	3	4.48
4	12	10.46
7	20	20.41

Q.E.D.
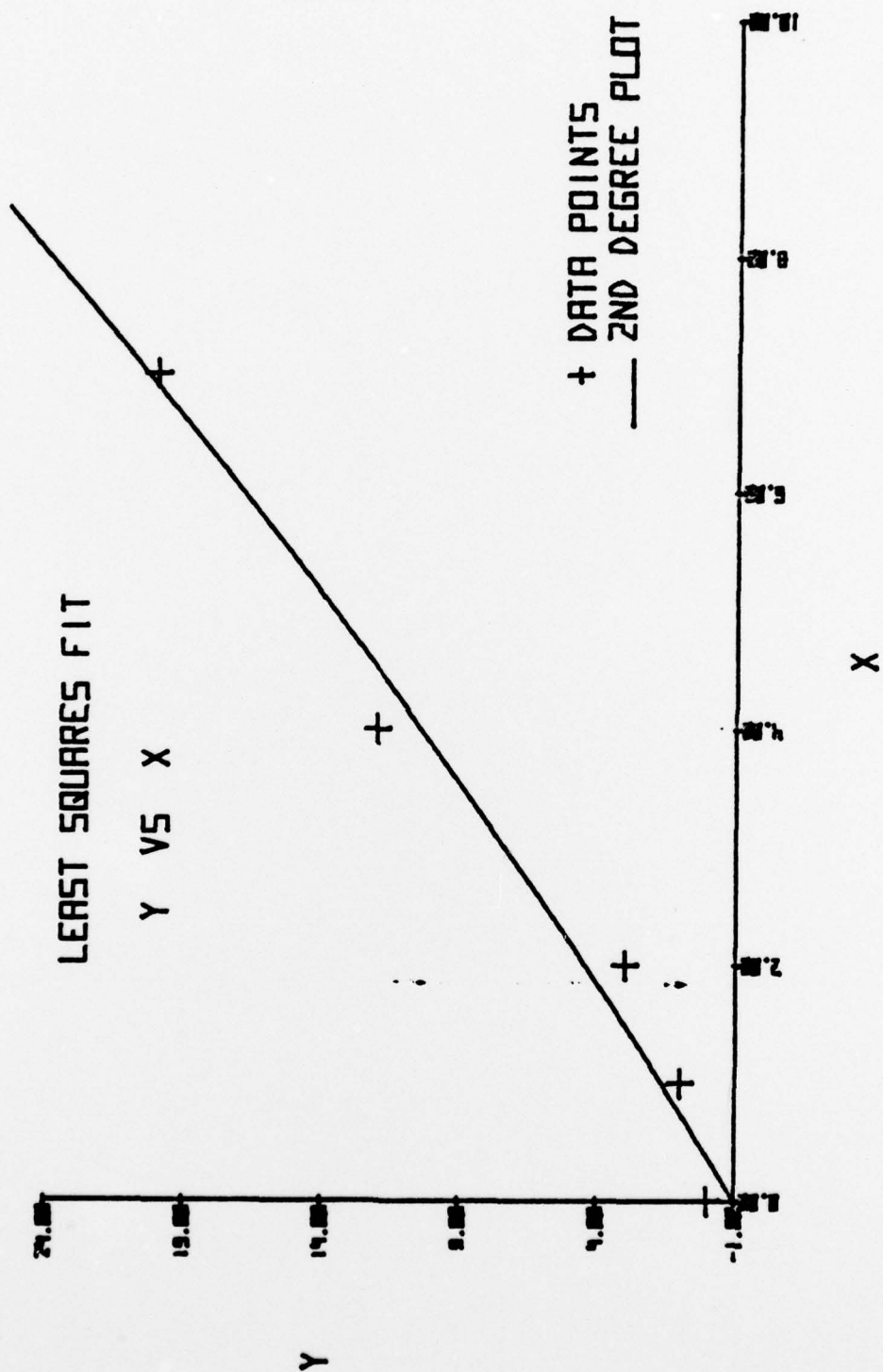
Figure XI   Least Squares Fit Example

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COMPUTER PROGRAM

```
1 PRINT " THIS PROGRAM COMPUTES ATE TAKE OFF ROLL AND VELOCITY. YOU WILL NEED"
2 PRINT "THE FOLLOWING INPUTS FOR THE COMPUTATION:"
3 PRINT
4 PRINT "1) RUNWAY PRESSURE ALTITUDE"
5 PRINT "2) RUNWAY TEMP IN DEG F"
6 PRINT "3) GROSS WT AND DOUBLE DATUM ON OR OFF"
7 PRINT "4) RELATIVE HUMIDITY"
8 PRINT "5) RUNWAY HEADING"
9 PRINT "6) WIND DIRECTION IN DEG MAG"
10 PRINT "7) WIND VELOCITY IN KTS"
11 PRINT "8) RUNWAY SLOPE IN %"
12 PRINT "9) A/C CG IN % MAC"
13 PRINT "10)T.E. FLAPS SETTING IN DEG"
14 PRINT
15 PRINT "IF YOU HAVE ALL THESE,PROCEED. WHEN COMPLETE CHECK YOUR ANSWER"
16 PRINT "AGAINST ATE NATOPS."
17 PRINT
18 DISP "PRESS ALT=";
19 INPUT A
20 IF A>8000 THEN 37
21 IF A<0 THEN 37
22 DISP "RUNWAY TEMP = ? DEG F";
23 INPUT B9
24 B=(B9-32)*5/9
25 IF B9>120 THEN 42
26 IF B9<0 THEN 42
27 B4=13.0863095227-0.0001711309*A-2.065456E-07*A↑2+3.68513616E-11*A↑3
28 B0=B4-2.4195714E-15*A↑4
29 B5=-0.045634924-7.8931012635E-06*A+3.75451107E-09*A↑2
30 B1=B5-9.7087859E-13*A↑3+6.9969745E-17*A↑4
31 B6=-0.0013167390-3.29503143E-07*A+4.0739193788E-10*A↑2
32 B2=B6-8.5487907730E-14*A↑3+5.4963903E-18*A↑4
33 B7=-1.9097E-05+1.36707502395E-08*A-9.46943763E-12*A↑2+2.043075E-15*A↑3
34 B3=B7-1.4617187626IE-19*A↑4
35 C=B0+B1*B+B2*B↑2+B3*B↑3
36 GOTO 47
37 PRINT
38 PRINT "RUNWAY ALT MUST  BE BTWN 0 AND 8000 FT, TRY AGAIN"
39 PRINT
40 PRINT "-------------------------------------------------"
41 GOTO 18
42 PRINT
43 PRINT "TEMP MUST BE BTWN 0 AND 120 DEG F, TRY AGAIN"
44 PRINT
45 PRINT "-------------------------------------------------"
46 GOTO 22
47 PRINT
48 PRINT "RUNWAY PRESS ALT =",A,"FT"
49 PRINT
50 PRINT "RUNWAY TEMP =",B9,"DEG F"
51 PRINT
52 PRINT "-------------------------------------------------"
53 DISP "IF DD ON ENTER 1, IF NOT ENTER 0";
54 INPUT D
55 IF D=1 THEN 60
56 IF D=0 THEN 64
```

```
57 PRINT "PLEASE ENTER 1 OR 0, TRY AGAIN"
58 PRINT
59 GOTO 53
60 E=1.49730484+0.50590325*C
61 PRINT "DOUBLE DATUM ON"
62 PRINT
63 GOTO 65
64 E=0.54177767+0.65875515*C
65 PRINT
66 PRINT "-------------------------------------"
67 DISP "GROSS WT=";
68 INPUT G
69 IF G>42000 THEN 81
70 IF G<20000 THEN 81
71 G2=-4.8896E+05+8.4974E+01*G-5.7856E-03*G↑2+1.9373E-07*G↑3-3.1744E-12*G↑4
72 G0=G2+2.0446E-17*G↑5
73 G3=5.8621E+04-1.0146E+01*G+6.8807E-04*G↑2-2.293E-08*G↑3+3.7387E-13*G↑4
74 G1=G3-2.3964E-18*G↑5
75 H=G0+G1*E
76 PRINT
77 PRINT "GROSS WT =",G,"LBS"
78 PRINT
79 PRINT "-------------------------------------"
80 GOTO 86
81 PRINT
82 PRINT "GROSS WT MUST BE BTWN 42000 AND 20000,TRY AGAIN"
83 PRINT
84 PRINT "----------------------------------------------"
85 GOTO 67
86 DISP "REL HUMIDITY =      %";
87 INPUT I
88 IF I<0 THEN 99
89 IF I>100 THEN 99
90 J=0
91 IF I<40 THEN 93
92 J=(I-40)/1000
93 K=H*J+H
94 PRINT
95 PRINT "REL HUMIDITY =",I,"%"
96 PRINT
97 PRINT "-------------------------------------------"
98 GOTO 104
99 PRINT
100 PRINT "REL HUMIDITY MUST BE BTWN 0 AND 100, TRY AGAIN"
101 PRINT
102 PRINT "------------------------------------------"
103 GOTO 86
104 DISP "ENTER RUNWAY HEADING";
105 INPUT Z
106 IF Z>360 THEN 135
107 IF Z<0 THEN 135
108 DISP "ENTER WIND DIRECTION IN DEG MAG";
109 INPUT Y
110 IF Y>360 THEN 135
111 IF Y<0 THEN 135
112 DISP "ENTER WIND VELOCITY";
113 INPUT X
114 W=ABS(Y-Z)
```

48

```
115 L=M/COS(2*PI*H/360)
116 IF L>40 THEN 130
117 IF L<-20 THEN 130
118 IF L=0 THEN 124
119 L0=-6.7124E+01+8.9509E-01*K+2.330GE-05*K↑2-1.6254E-09*K↑3+3.3720E-14*K↑4
120 L1=-9.0995-1.0856E-02*K+2.1754E-07*K↑2-2.5327E-11*K↑3+1.197E-15*K↑4
121 L2=1.4782E-01-2.1606E-06*K+3.4274E-09*K↑2-2.7817E-13*K↑3+9.3077E-18*K↑4
122 M=L0+L1*L+L2*L↑2
123 GOTO 125
124 M=K
125 PRINT
126 PRINT "HEADWIND =",L,"KTS"
127 PRINT
128 PRINT "----------------------------------------"
129 GOTO 140
130 PRINT
131 PRINT "HEADWIND MUST BE BTWN -20 AND +40 KTS, TRY AGAIN"
132 PRINT
133 PRINT "----------------------------------------"
134 GOTO 108
135 PRINT
136 PRINT "MAG HEADINGS MUST BE BTWN 0 AND 360, TRY AGAIN"
137 PRINT
138 PRINT "----------------------------------------"
139 GOTO 104
140 DISP "R/W SLOPE = (+ FOR UP,-FOR DN)";
141 INPUT N
142 IF N>2 THEN 153
143 IF N<-2 THEN 153
144 O0=4.5704E+01+9.3429E-01*M+2.2265E-05*M↑2-2.338E-09*M↑3+7.941E-14*M↑4
145 O1=7.9472+1.4914E-02*M+9.0708E-06*M↑2-7.1235E-10*M↑3+3.0684E-14*M↑4
146 O2=5.3616-8.5136E-03*M+3.5914E-06*M↑2-4.5932E-10*M↑3+1.9889E-14*M↑4
147 O=O0+O1*N+O2*N↑2
148 PRINT
149 PRINT "RUNWAY SLOPE =",N,"%"
150 PRINT
151 PRINT "----------------------------------------"
152 GOTO 158
153 PRINT
154 PRINT "R/W SLOPE MUST BE BTWN -2 AND 2, TRY AGAIN"
155 PRINT
156 PRINT "----------------------------------------"
157 GOTO 140
158 DISP "ENTER A/C CG(20 TO 35 %MAC)";
159 INPUT P
160 IF P>35 THEN 171
161 IF P<20 THEN 171
162 O0=2.6042E+03-2.1694*O+1.0915E-03*O↑2-1.1119E-07*O↑3+3.662E-12*O↑4
163 O1=-1.7573E+02+2.2601E-01*O-7.5225E-05*O↑2+7.7018E-09*O↑3-2.5437E-13*O↑4
164 O2=2.8549-4.0102E-03*O+1.2832E-06*O↑2-1.3234E-10*O↑3+4.3908E-15*O↑4
165 O=O0+O1*P+O2*P↑2
166 PRINT
167 PRINT "CG =",P,"%MAC"
168 PRINT
169 PRINT "----------------------------------------"
170 GOTO 176
171 PRINT
172 PRINT "CG MUST FALL BTWN 20 AND 35%MAC, TRY AGAIN"
173 PRINT
174 PRINT "----------------------------------------"
175 GOTO 158
```

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```
176 DISP "ENTER TE FLAP SETTING(20 TO 40)";
177 INPUT R
178 IF R>40 THEN 201
179 IF R<20 THEN 201
180 S0=-4.0079E+02+1.5801*0-2.0254E-04*0↑2+2.4111E-08*0↑3-8.6737E-13*0↑4
181 S1=1.6196E+01-2.4333E-02*0+9.3484E-06*0↑2-1.2594E-09*0↑3+4.7522E-14*0↑4
182 S2=-1.4758E-01+2.359E-04*0-1.037E-07*0↑2+1.6016E-11*0↑3-6.3195E-16*0↑4
183 S=S0+S1*R+S2*R↑2
184 T1=(INT(S/100))*100
185 T2=S-T1
186 IF T2>0 THEN 189
187 T=S
188 GOTO 190
189 T=((T1/100)+1)*100
190 PRINT
191 PRINT "TE FLAP SETTING =",R,"DEG"
192 PRINT
193 PRINT "------------------------------------------"
194 PRINT "------------------------------------------"
195 PRINT
196 PRINT "ADJUSTED GROUND ROLL =",T,"FT(ROUNDED UP TO NEAREST 100 FT)"
197 PRINT
198 PRINT "------------------------------------------"
199 PRINT "------------------------------------------"
200 GOTO 206
201 PRINT
202 PRINT "TE FLAP SETTING MUST BE BTWN 20 AND 40 DEG, TRY AGAIN"
203 PRINT
204 PRINT "------------------------------------------"
205 GOTO 176
206 U1=5.4023E+01+3.4787E-03*G-1.9475E-08*G↑2
207 U=U1+(26-P)/2
208 V0=-1.9171E+03+6.1604E+01*U-7.0348E-01*U↑2+3.5661E-03*U↑3-6.6578E-06*U↑4
209 V1=7.6824E+01-2.4517*U+2.8779E-02*U↑2-1.4753E-04*U↑3+2.7872E-07*U↑4
210 V2=-7.2239E-01+2.3415E-02*U-2.798E-04*U↑2+1.4596E-06*U↑3-2.807E-09*U↑4
211 V3=V0+V1*R+V2*R↑2
212 V4=INT(V3)
213 IF V3-V4=0 THEN 216
214 V=V4+1
215 GOTO 217
216 V=V3
217 PRINT
218 PRINT "TAKEOFF VELOCITY =",V,"KIAS (ROUNDED UP TO THE NEAREST 1 KT)"
219 PRINT
220 PRINT "------------------------------------------"
221 GOTO 18
222 END
```

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